LOW TEMPERATURE PERFORMANCE OF A 12-BIT SERIAL CMOS ANALOG-TO-DIGITAL CONVERTER

Test Report

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Background

Power processing electronic systems, data acquisition probes, and signal conditioning circuits are required to operate reliably under harsh environments in many of NASA's missions. The environment of the space missions as well as the operational requirements of some of the electronic systems, such as infrared-based satellites or telescopic observation stations where cryogenics are involved, dictate the utilization of electronics that can operate efficiently and reliably at low temperatures. In this work, a Burr-Brown ADS7808 analog-to-digital (A/D) converter was characterized in terms of voltage conversion and signal timing as a function of temperature. This device is a 12-bit, 100 kHz sampling converter with CMOS-based structure. It can output data either by using an internal clock or synchronized to an external data clock. The low temperature performance of the converter was investigated initially by utilizing the built-in reference voltage and then by using an external source to serve as the reference voltage.

Test Setup

The ADS7808 converter, which is rated for operation between –40 °C and +85 °C, was evaluated from room temperature to -190 °C in a liquid nitrogen cooled chamber. Test were performed at temperatures of 25, 0, -25, -50, -75, -100, -125, -150, -175, and -190 °C. At each test temperature, the device was allowed to soak for 10 minutes before measurements were made.

The device was evaluated in terms of its voltage conversion and control signal timing at a switching frequency of 100 kHz. For simplification, only DC values from 0 to 10.1 V were applied to the analog input of the converter. For each DC analog input value, the A/D converter produced an effective output bit pattern in binary format that was captured by a digital oscilloscope. At each test temperature, a certain input voltage in the range of 0 to 10.1V was applied to the converter and the corresponding digital output was recorded. A factor of 2.442 mV/bit was used for the binary/decimal output conversion. In addition, the control signal timing associated with the operation of the converter were also monitored. These signals included the R/C (Read/Convert Input), DATACLK (Data Clock), SDATA (Serial Output Data), and BUSY (Busy Output). The timing characteristics that were investigated in this work included the BUSY Delay (t2), BUSY Low (t3), R/C Low to DATACLK Delay (t8), DATACLK Period (t9), and the Data Valid to DATACLK High Delay (t10). Relationship between these conversion and data timing is illustrated in Figure 1, and the manufacturer's specification for these characteristics is listed in Table I.

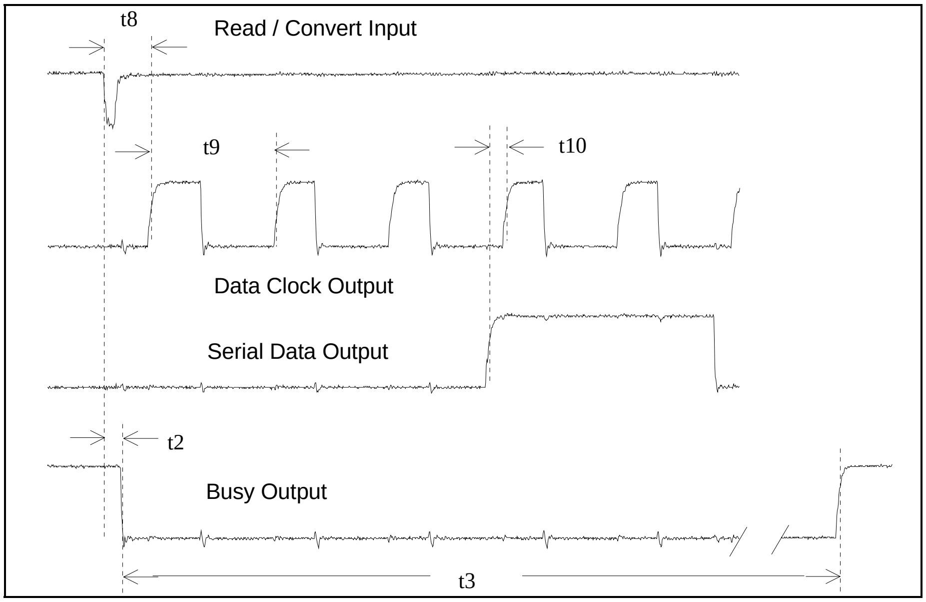

Figure 1. Control and data waveforms illustrating timing.

Table I. Manufacturer's specification of conversion and data timing.

Timing	Description	Min	Typ	Max	units
t2	BUSY Delay			65	ns
t3	BUSY Low			8	μs
t8	R/C Low to DATACLK Delay		450		ns
t9	DATACLK Period		440		ns
t10	Data Valid to DATACLK High Delay	20	75		ns

Results and Discussion

The output voltage of the converter was obtained as a function of the input voltage in the temperature range of +25 °C to –190 °C. In general, the analog output level tracks its digital input counterpart quite well at test temperatures between 25 °C and –75 °C. It should be noted that the test setup and measurement system displayed an approximate error of about 20 to 50 mV. At temperatures of –100 °C and beyond, however, some deviation occurs in the signal conversion accuracy. For example, the values of the output voltage, in binary as well as decimal format, corresponding to an input variation from zero to 10.1 volts are listed in Table II at three different temperatures; namely 25, -100, and –190 °C. Waveforms of the actual control and serial data output signals obtained at 25 °C and -190 °C are shown in Figures 2 and 3, respectively. Changes in the waveforms resulting from the low temperature exposure include the appearance of spikes along the clock signal and a decrease in its periodic timing.

Table II. Converted output voltage (using internal voltage reference) at various temperatures.

Input Voltage (V)	Output Voltage @ 25 °C		Output Voltage @ -100 °C		Output Voltage @ -190 °C	
	Binary	Decimal	Binary	Decimal	Binary	Decimal
0	0	0.000	0	0.000	4	0.009
0.5	208	0.508	256	0.518	228	0.513
1	412	1.006	507	1.026	448	1.008
2	821	2.005	1008	2.041	894	2.012
5	2048	5.001	2516	5.094	2227	5.013
7.25	2972	7.258	3648	7.385	3248	7.311
10	4095	10.000	4095	8.290	4095	9.218
10.1	4095	10.000	4095	10.000	4095	10.000

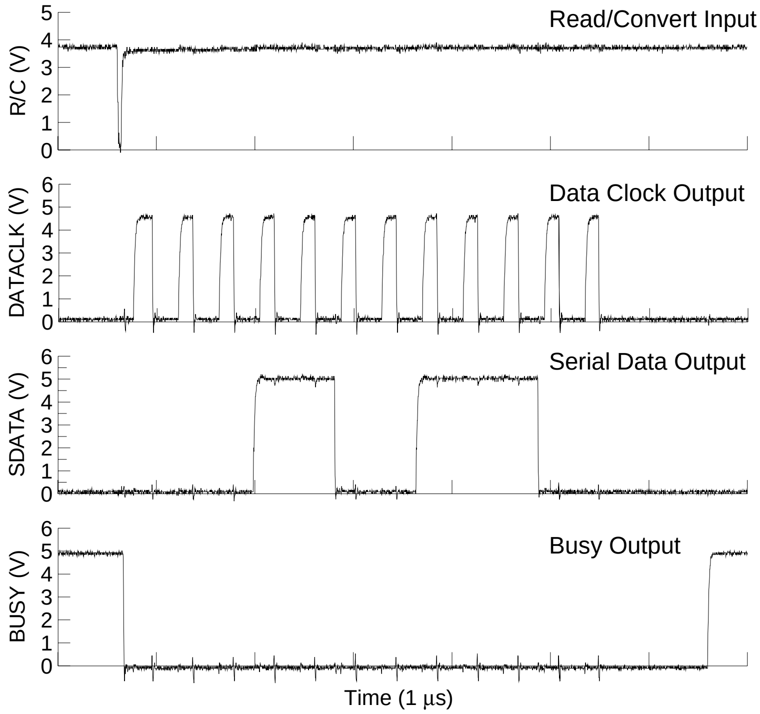

Figure 2. Waveforms of control and data signals at 25 °C.

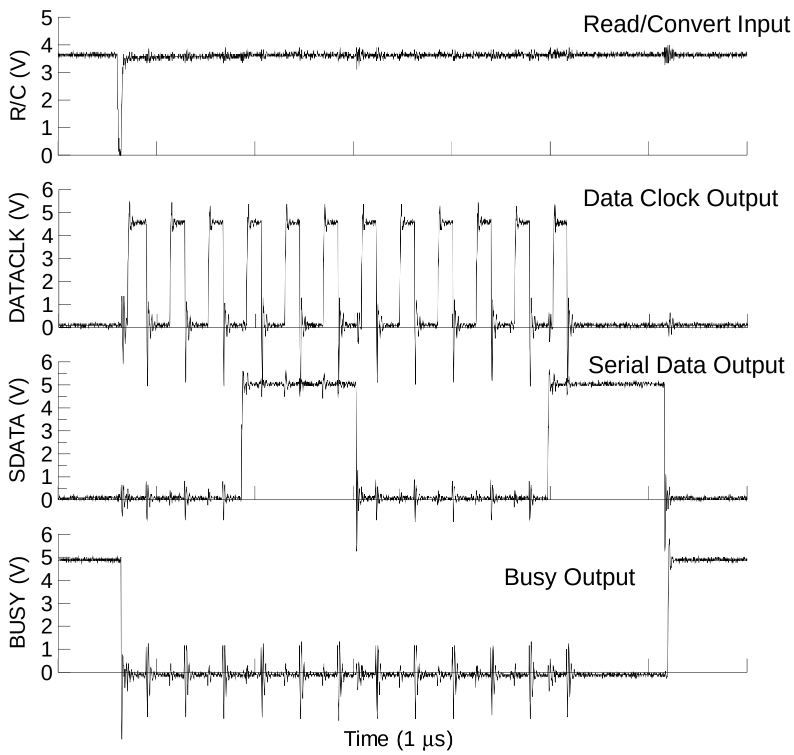

Figure 3. Waveforms of control and data signals at -190 °C.

The converted outputs, which were reported thus far, were obtained utilizing the chip built-in reference. The dependence of this internal voltage reference on the test temperature is shown in Figure 4. It can be clearly seen that it remains relatively steady till about -75 °C. Beyond that temperature, it initially drops and then fluctuations follow.

The control signal timing as a function of temperature are shown in Table III. It is evident that all of these times decrease with decreasing temperature. It is important to point out that with the exception of t8, the values of these time variables, at all test temperatures, fall within or close to the manufacturer's specifications, as listed in Table I. The average value obtained for the R/C Low to DATACLK Delay (t8), which is typically specified at 450 ns, decreased from 164 ns at 25 °C to 96 ns at –190 °C. It is not clearly understood why this timing variable was out of its specified value.

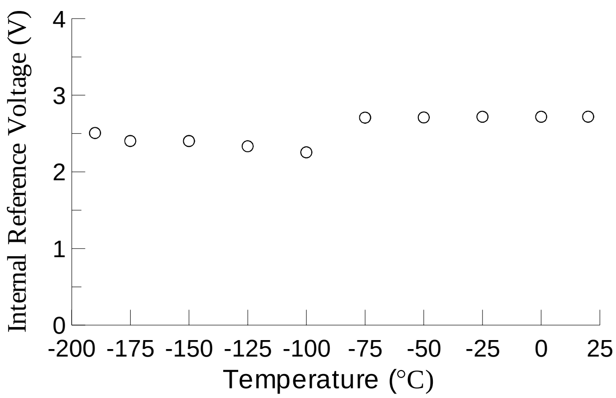

Figure 4. Internal reference voltage vs temperature.

Temp (°C)	t2 (ns)	t3 (μs)	t8 (ns)	t9 (ns)	t10 (ns)
25	60	5.94	164	460	60
0	54	5.88	150	452	56
-25	52	5.84	142	450	54
-50	48	5.78	134	446	56
-75	44	5.72	122	442	52
-100	40	5.68	112	438	48
-125	36	5.62	106	436	48
-150	34	5.58	100	432	46
-175	32	5.58	96	430	44
-190	32	5.56	96	430	44

Table III. Signal timing vs temperature.

The voltage conversion capability of the device was also tested with an external source serving as the reference voltage. In this case, the analog output level tracks its digital input counterpart quite well at all temperatures in the test range of 25 °C to –190 °C. For example, the values of the output voltage, in binary as well as decimal format, corresponding to an input variation from zero to 10.1 volts are listed in Table IV at three different temperatures; namely 25, -100, and –190 °C. The performance of the device under this condition appears to be much better than that observed when the internal reference voltage was used. The dependence of the external voltage reference and its current on the test temperature are shown in Figure 5 and 6, respectively. It can be clearly seen that while the voltage remains relatively steady throughout the temperature range, the reference current tends to hold a value of about 1.5 μA only in the temperature range of 25 °C to –100 °C. At the next test temperature, i.e. –125 °C, the current jumps to about 110 μA but decreases as temperature is further decreased. At –190 °C, the value of this current reaches about 64 μA. The maximum value of this external reference current drain specified by the manufacturer is 100 μA in the temperature range of -40 °C to 85 °C.

Table IV. Converted output voltage (using an external voltage reference) at various temperatures.

Input Voltage (V)	Output Voltage @ 25 °C		Output Voltage @ -100 °C		Output Voltage @ -190 °C	
	Binary	Decimal	Binary	Decimal	Binary	Decimal
0	3	0.007	4	0.010	4	0.010
0.5	207	0.505	204	0.498	208	0.508
1	411	1.004	412	1.006	411	1.004
2	819	2.000	820	2.002	816	1.993
5	2045	4.994	2045	4.994	2048	5.001
7.25	2965	7.241	2960	7.228	2959	7.226
10	4088	9.983	4080	9.963	4080	9.963
10.1	4095	10.000	4095	10.000	4095	10.000

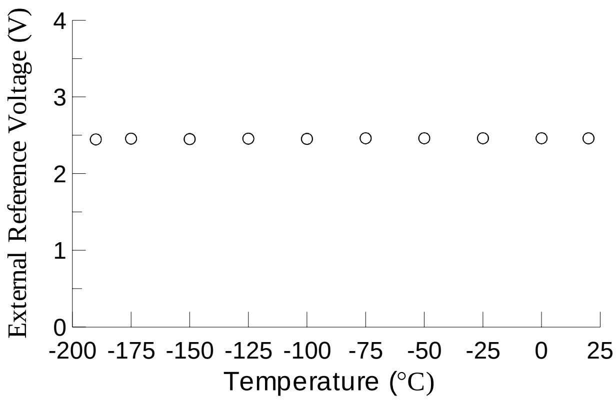

Figure 5. External reference voltage vs temperature.

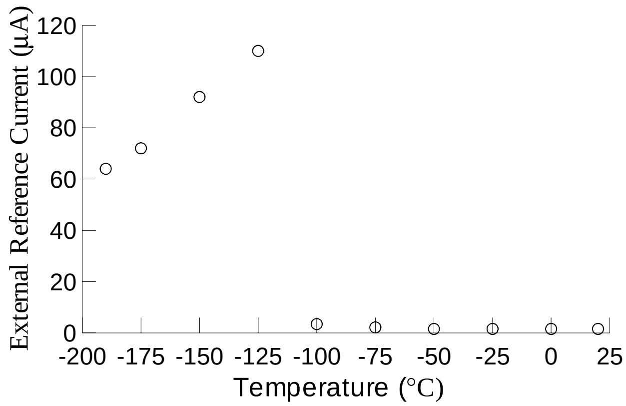

Figure 6. External reference current vs temperature.

Selection of the reference voltage (internal or external) seems to have no impact on the control and data timing, at any given test temperature, as they maintained the values listed in Table III.

Conclusion

A CMOS, 12-bit, 100 kHz sampling analog-to-digital converter has been investigated for suitability for use in low temperature environments. The BURR-BROWN ADS7808 A/D converter was evaluated in terms of its voltage conversion and control signal timing characteristics in the temperature range of 25 °C to -190 °C. The device was initially tested using the internal reference, and then by using an external source to serve as the reference voltage. The data indicates that the device performed reasonably well throughout the entire test temperature range of 25 °C to -190 °C. When the reference voltage was supplied internally, this voltage exhibited some fluctuations at temperatures below -75 °C. As a result, the internal conversion factor of the device changed accordingly. Nonetheless, the chip continued to operate without any major degradation in performance or catastrophic failure. Improvement in device performance was observed at low temperatures when the reference voltage, which held steady, was supplied externally. The preliminary results have shown that this A/D converter may be considered as a potential candidate for operation at low temperatures down to -190 °C, well below the manufacturer's minimum specified operating temperature. More comprehensive testing is, however, required to fully characterize its performance under long-term low temperature exposure and thermal cycling so that its suitability and reliability for low temperature space and commercial applications are determined.

References

1. ADS7808 Data Sheet, PDS-1155B, BURR-BROWN Corporation.

Acknowledgments

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